

Developmental History of a New Family of Subscale, Convertible, High Performance UAVs

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*Micro Aerial Vehicles -- Unmet Technological requirements
Schloß Elmau, Germany 22 - 24 September 2003*

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 23 JUL 2004	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE Developmental History of a New Family of Subscale , Convertible, High Performance , UAVs		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Aerospace Engineering Department Aerospace Engineering Department Auburn University, Alabama Auburn University, Alabama USA		8. PERFORMING ORGANIZATION REPORT NUMBER	
		9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	
		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			
13. SUPPLEMENTARY NOTES See also ADM001689, EOARD-CSP-03-5073 Micro Air Vehicle Workshop., The original document contains color images.			
14. ABSTRACT			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	UU
			18. NUMBER OF PAGES 25
			19a. NAME OF RESPONSIBLE PERSON

Outline



1989 - '96 Enabling Materials and Experience

1994 - '97 The First DoD MAV

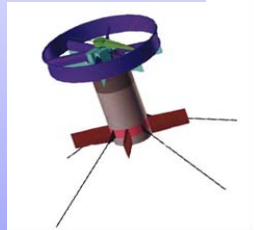
1998 - '00 DARPA's MOUT MAVs

2001 - '03 Convertible Military MiAVs

2003 X/YQ-138 Handoff to Industry



Kolbri



LuMAV



XQ-138 Launch



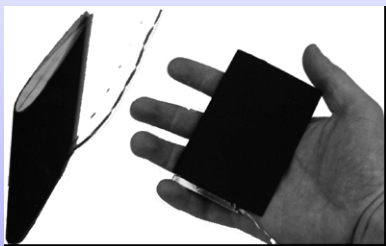
YQ-138 Weapon Firing

1989 - '96 Enabling Materials and Experience

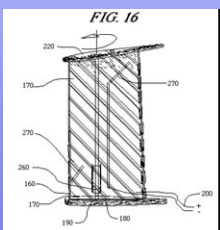


USAF commissions 1st DAP missile fin study

1st torque-plate rotor built ($\pm 5^\circ$ static deflections)



1st prototype pitch-active missile fin ($\pm 5^\circ$ static deflections)



1989

1st twist-active adaptive wing built & bench tested ($\pm 0.8^\circ$ static twist deflections)

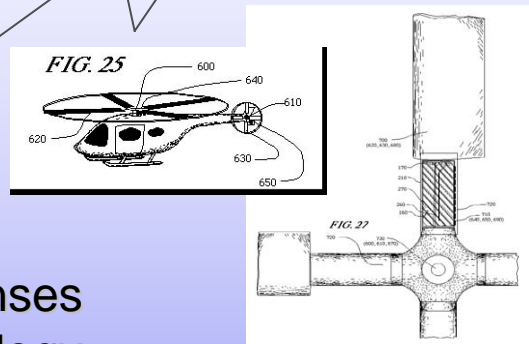
1990

1st twist-active rotor blade assembled & tested

1991

GD licenses DAP technology

1992



1993

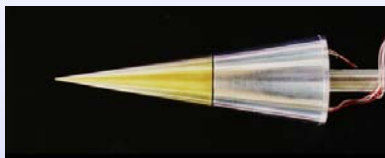


Directional Attachment invented to generate twist deflections in aerodynamic surfaces

1989 - '96 Enabling Materials and Experience



Gamara, the first helicopter to use adaptive materials for all flight control



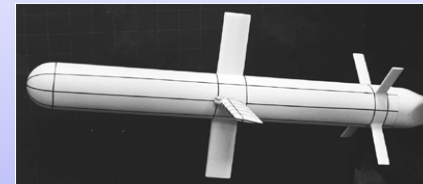
Adaptive gravity weapons



1996

Piezoceramic lamina hardening techniques invented for Barrel Launched Adaptive Munition (BLAM) program

Adaptive TOW-2B



1995



NSF sponsors UAV & DAP rotor work

1994



DAP torque-plate rotor demonstrates $\pm 8^\circ$ static and dynamic deflections at up to 2.5/rev on Froude & Mach scaled rotors
Mothra, the first aircraft to use adaptive materials for all flight control

1994 - '97 The First DoD MAV

Kolibri

High voltage tether

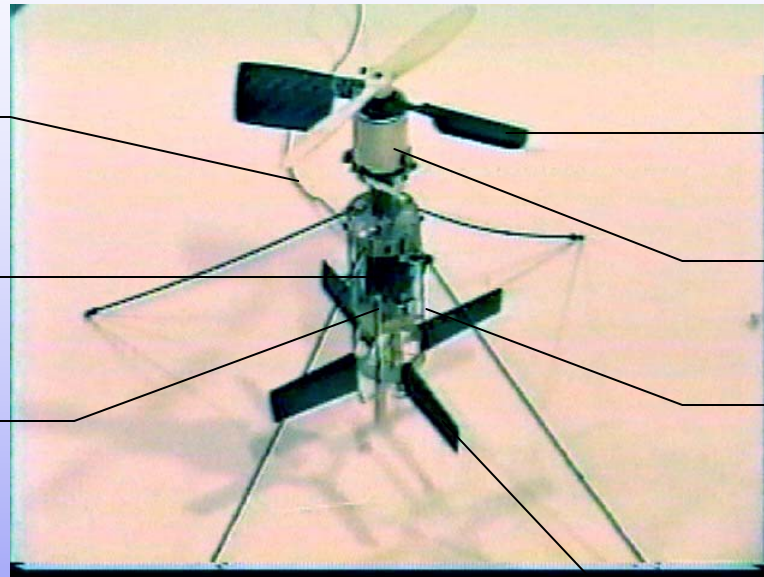
CCD camera

Piezoelectric gyros

Counterrotating rotor

High voltage rare-earth electric motor

Graphite truss



Kolibri Airborne Camera View



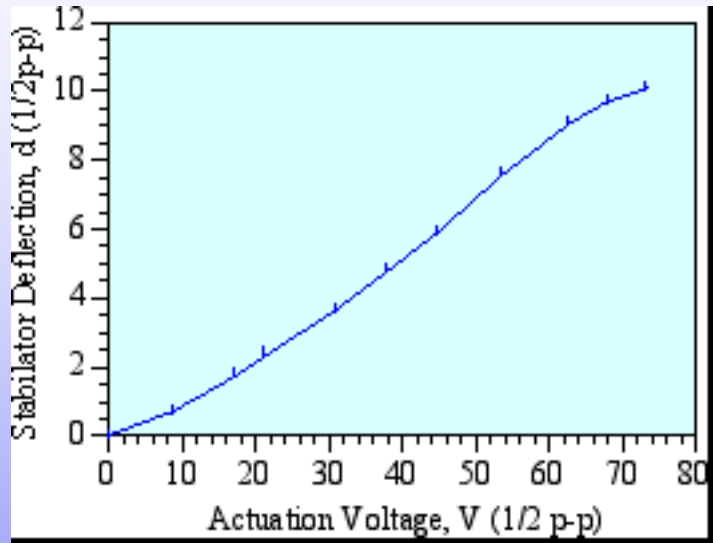
Piezoelectric stabilators



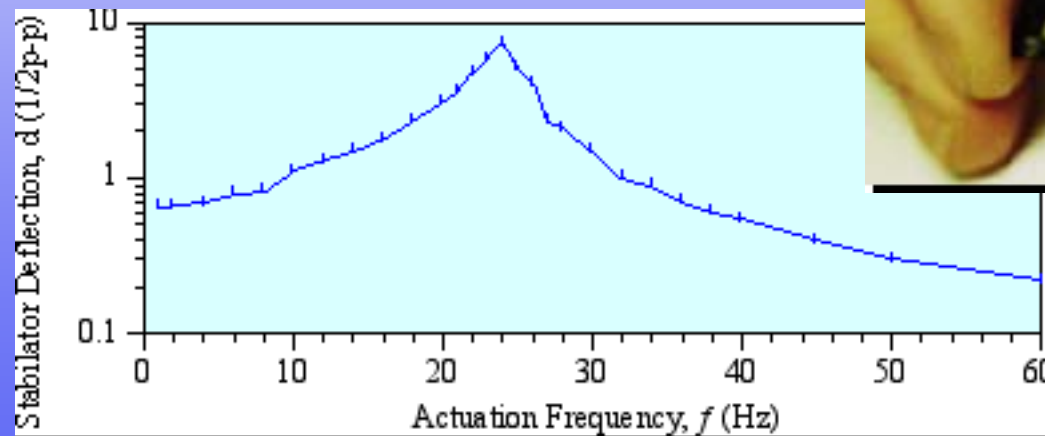
1st Flight September 1997

1994 - '97 The First DoD MAV

Enabling Technology: *High Speed Piezoelectric Stabilators*



- first natural frequency in pitch: 23 Hz
- pitch corner frequency: 47 Hz
- max power consumption: 14 mW
- max. static deflections: $\pm 11^\circ$
- total mass 5.2g
- actuator mass: 380 mg



1998 - 2000 DARPA's MOUT MAVs

Mission Challenge: reconnaissance in urban and subcanopy environments

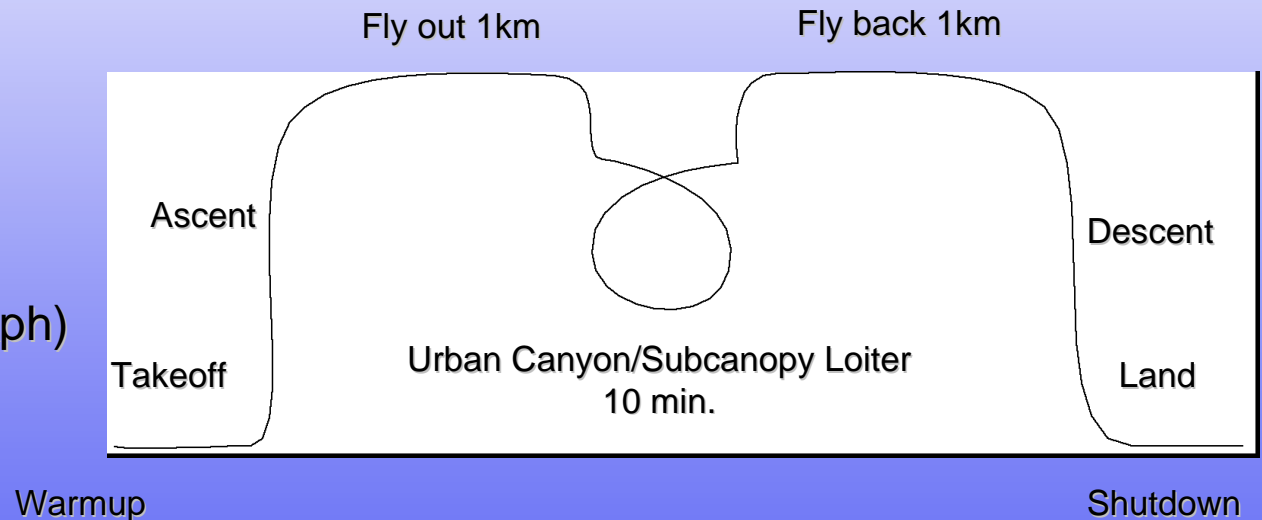
"Military Operations in Urban Terrain is one of the top priorities for the DoD."

-Lt. Gen. Bruce Knutson, USMC Nov. 1999

Mission Specification:

- Max. 6" (15cm) dia. rotor
- Max. Range: 1km
- Max. Endurance: 20 min.
- All weather capable
- 15g wall strike
- T/O distance: n/a
- Max flight speed: 30 mph (48kph)
- Com link: RF
- Flight modes: 1st, 3rd person
- Sensor: B/W 0.1 lux

Mission Profile:



1998 - 2000 DARPA's MOUT MAVs

Motivation:

"2/3 of eligible targets in the Balkans went undetected, let alone unengaged because of our reconnaissance deficiencies."

-Lt. Gen. Bruce Knutson, USMC Nov. 1999



Current UAVs offer monocular situational awareness with only one general view -- from above.



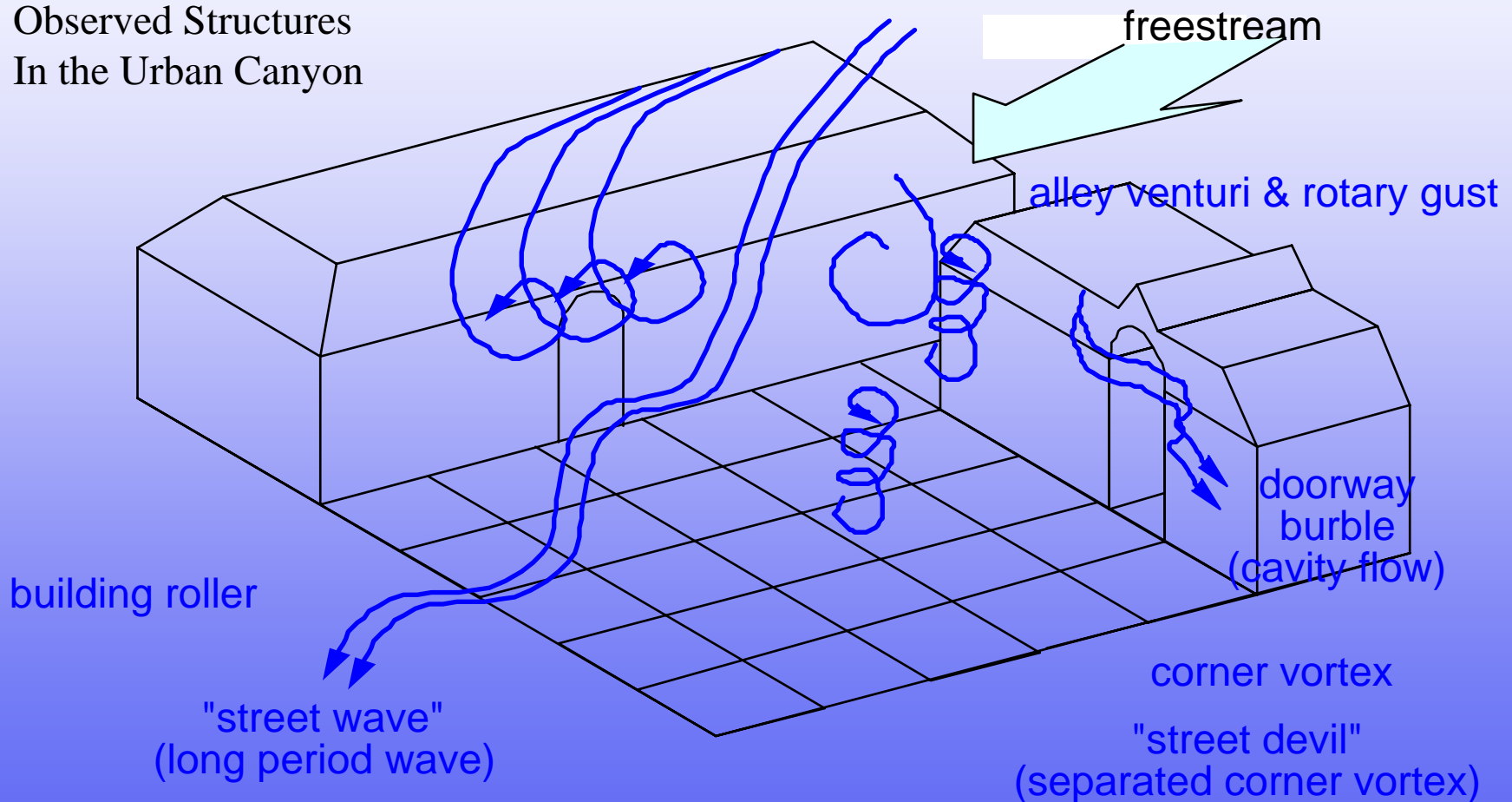
Panocular situational awareness is necessary in the modern battlefield.

M998 HMM W V Aerial Detection Exercise, Alabama July 1998

1998 - 2000 DARPA's MOU/MAVs

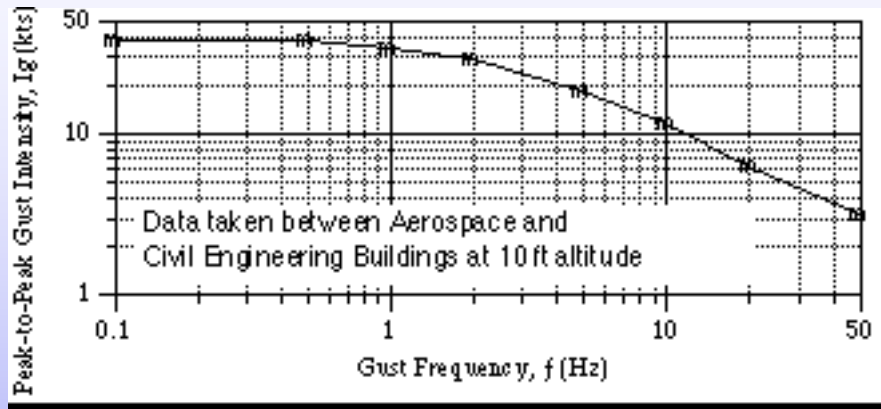
Environmental Survey:

Observed Structures
In the Urban Canyon

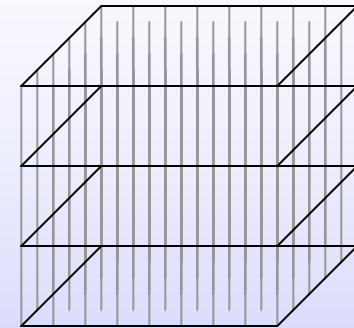


1998 - 2000 DARPA's MOUT MAVs

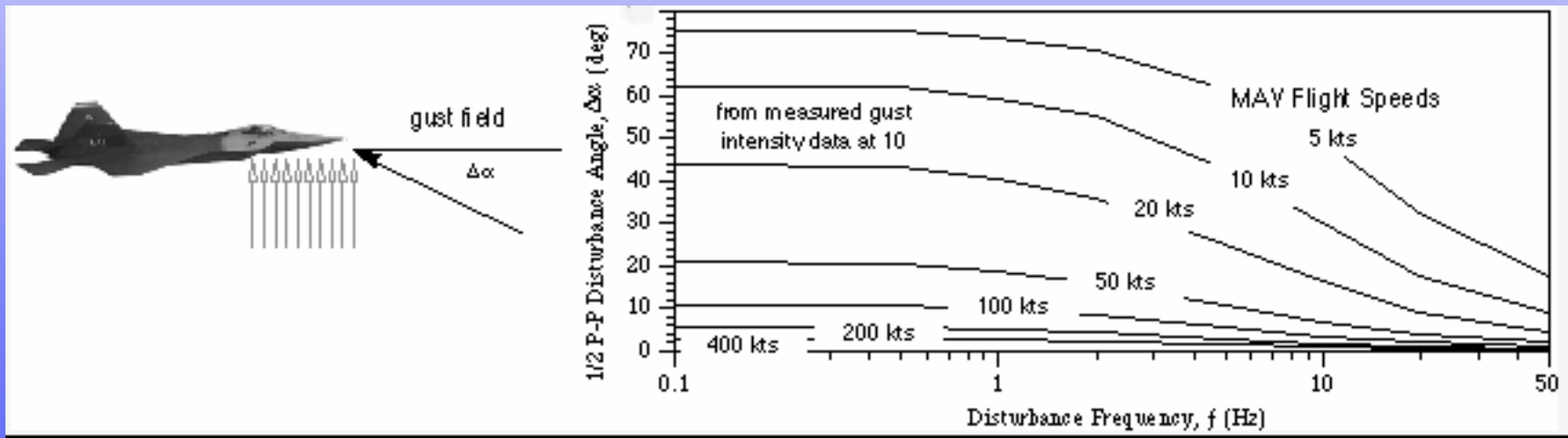
MOUT & Subcanopy MAV Configuration Selection



Isotropic Gust Grid:
363 sample points



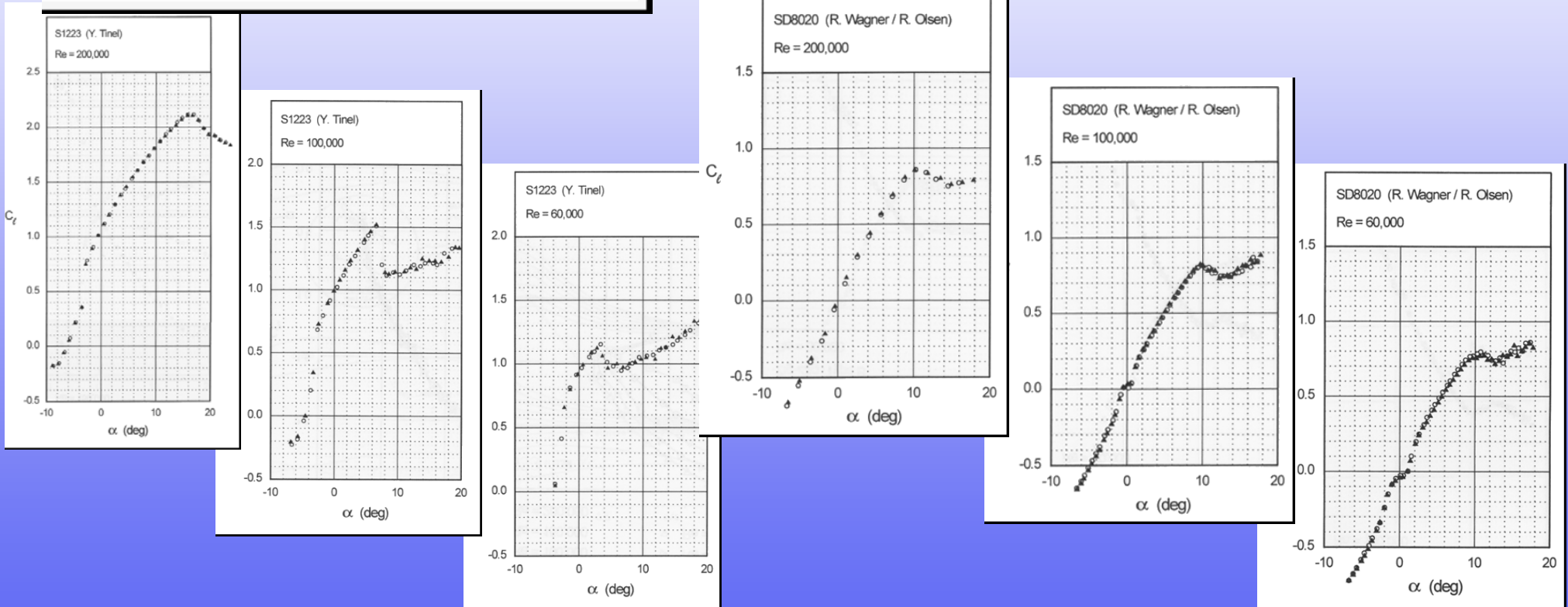
100 ft x 100 ft x 30 ft high (30m x 30m x 9m high)
1 min. per point, 10 days of sampling
Blue sky sampling days only



1998 - 2000 DARPA's MOUT MAVs

MOUT & Subcanopy MAV Configuration Selection

Aerodynamics Challenges: Low C_{lmax} at Low Re ... gusts... and rain



1998 - 2000 DARPA's MOUT MAVs

MOUT & Subcanopy MAV Configuration Selection: Turn Radii Required

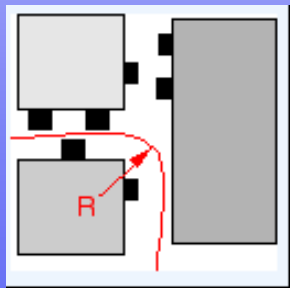
Urban Setting Survey

200 intersections in Groningen, Netherlands
within 1km of Station Nord



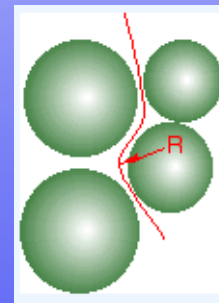
Subcanopy Survey

200 trees in the Tuskegee National Forest along
Bartram National Recreation Trail



Aircraft Turn Radii

-1 Std Dev.	Average	+1 Std Dev.
6.1ft	8.7ft	14.4ft
1.9m	2.7m	4.4m



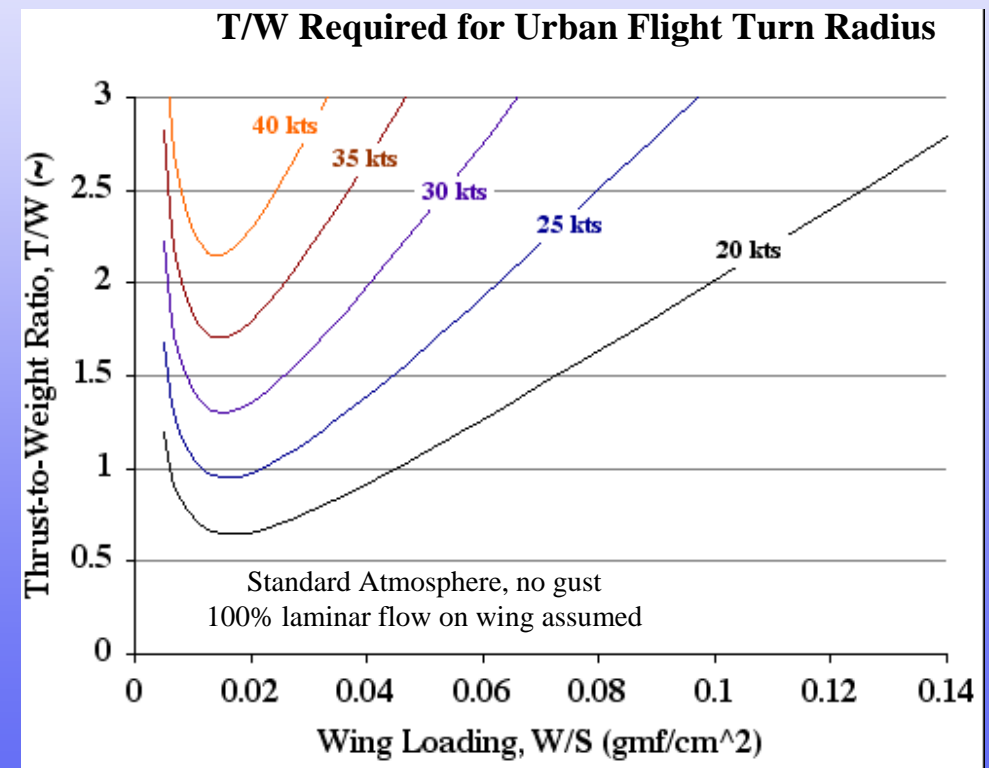
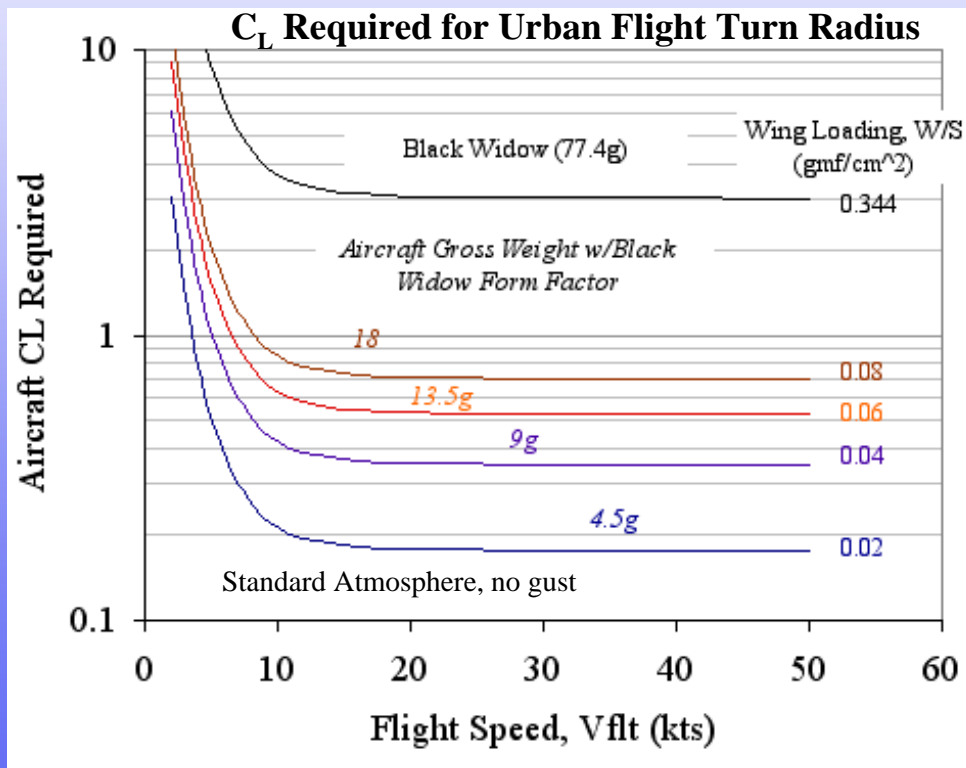
Aircraft Turn Radii

-1 Std Dev.	Average	+1 Std Dev.
8.8ft	14.7ft	32.9ft
2.7m	4.5m	10m

1998 - 2000 DARPA's MOUT MAVs

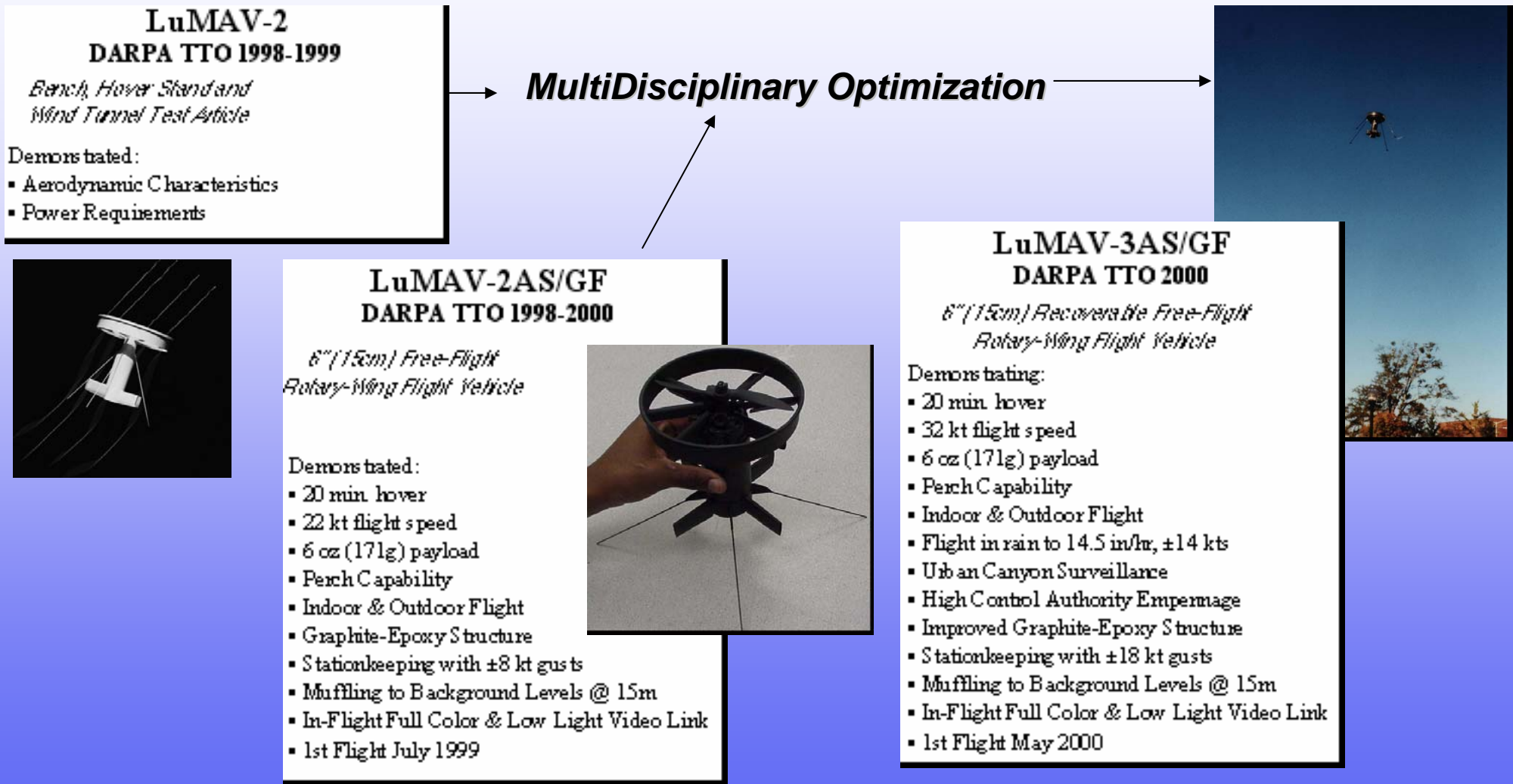
MOUT & Subcanopy MAV Configuration Selection:

- CURRENT FIXED-WING MAVs CANNOT MAKE THE TURNS IN URBAN TERRAIN
- FUTURE FIXED-WING MAVs REQUIRE $T/W > 1$ TO NAVIGATE URBAN TERRAIN



1998 - 2000 DARPA's MOUT MAVs

MOUT & Subcanopy MAV Configuration Selection: COLEOPTER

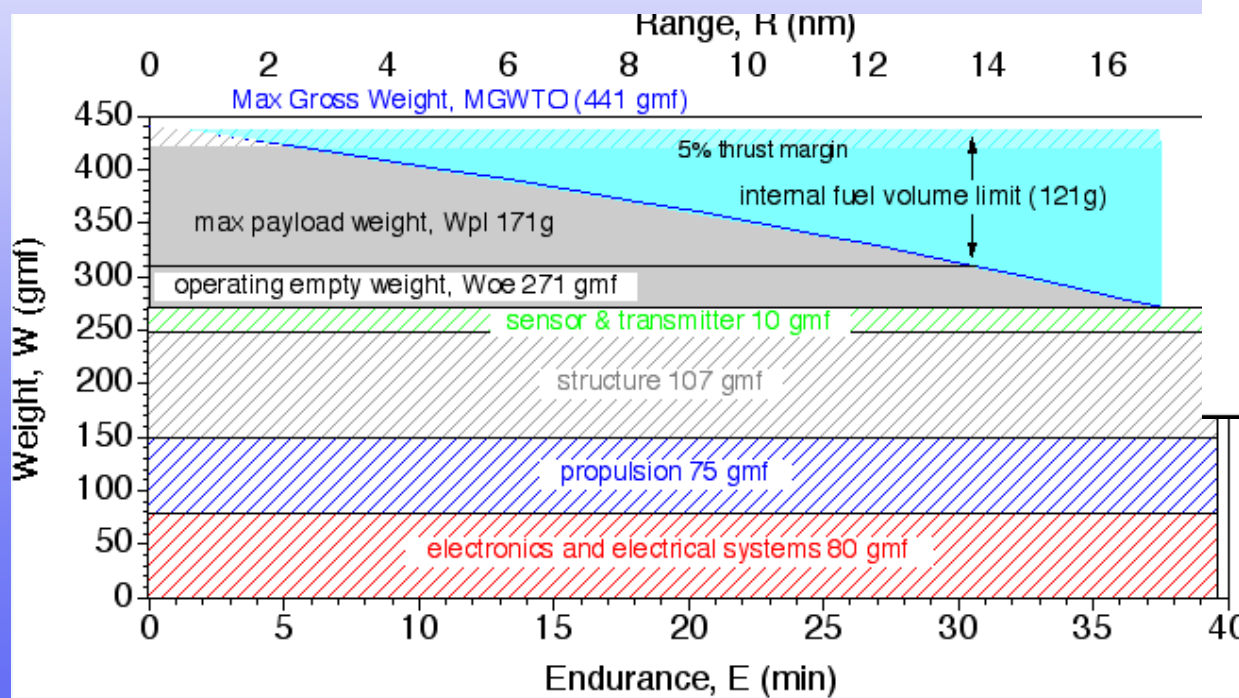
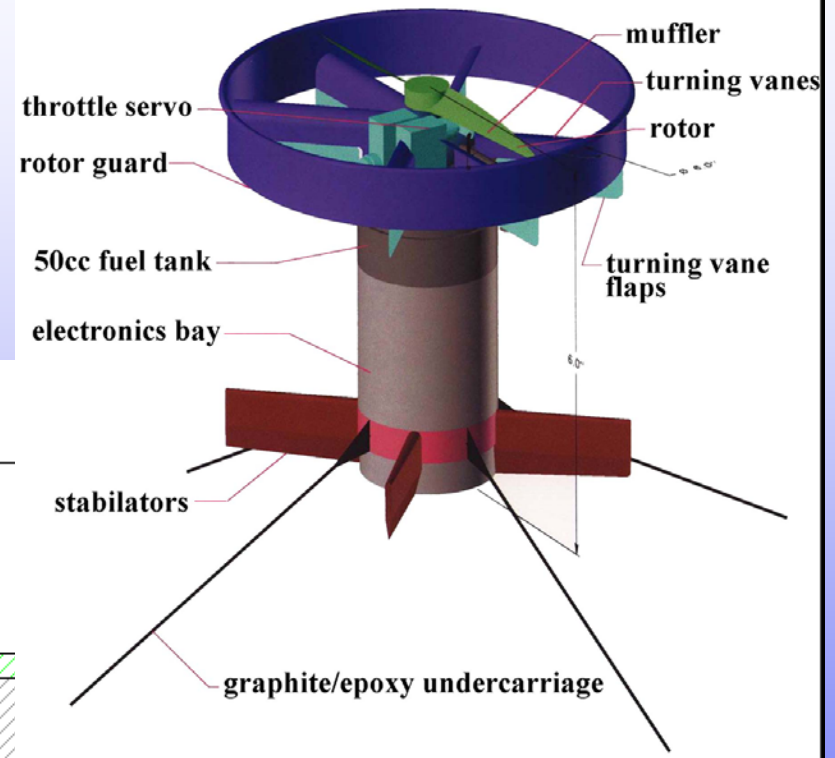


1998 - 2000 DARPA's MOU T MAVs



MultiDisciplinary Optimization Performed on:

- Structures
- Aerodynamics
- S&C
- Propulsion

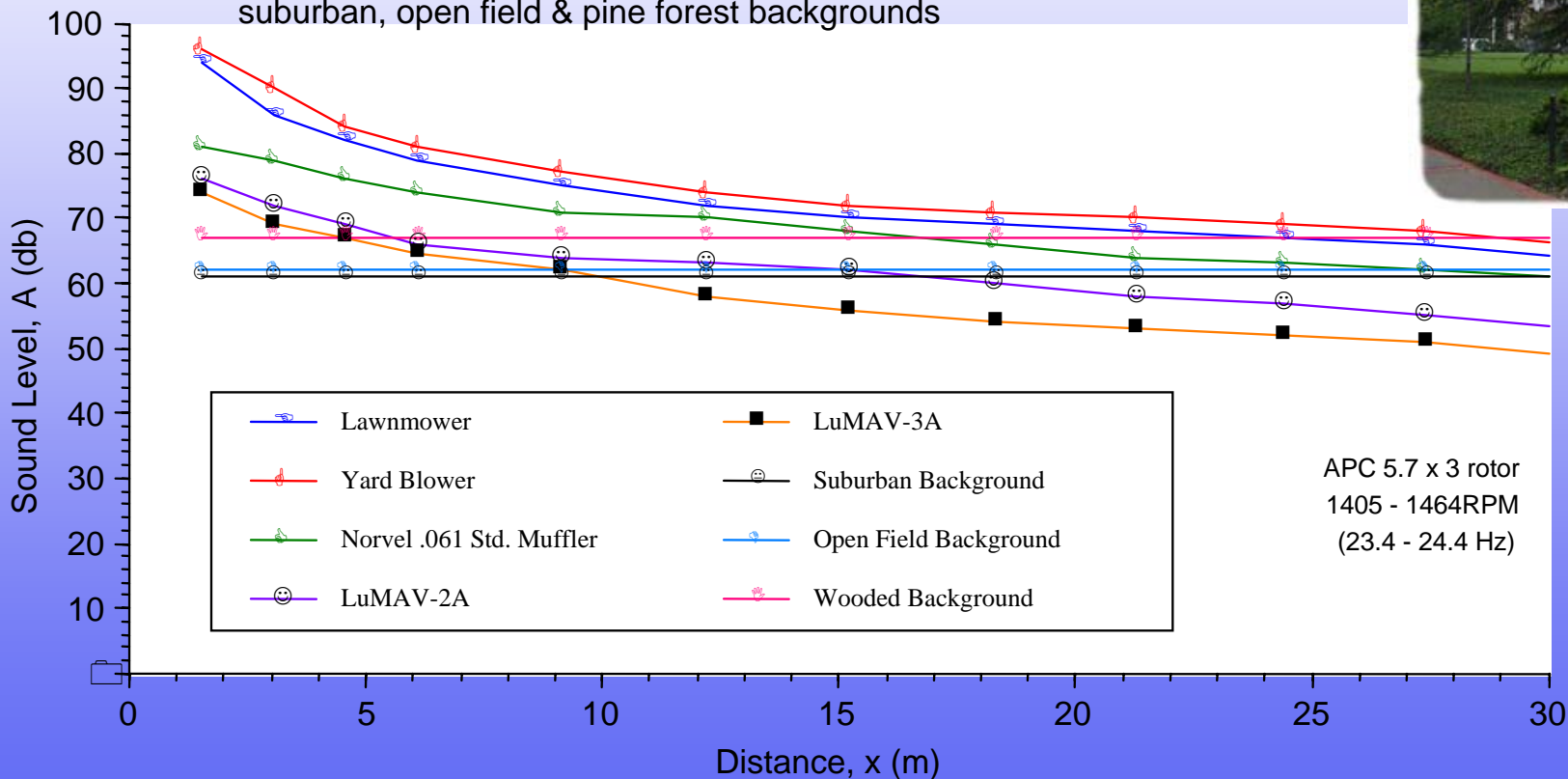


1998 - 2000 DARPA's MOUT MAVs

LuMAV Testing

acoustic signature

test conditons:
 72 - 78°F day, 65% humidity
 winds 3 - 6 kts & variable, 9:00 - 11:00 am
 testing conducted: East Central Alabama in March
 suburban, open field & pine forest backgrounds



APC 5.7 x 3 rotor
 1405 - 1464RPM
 (23.4 - 24.4 Hz)

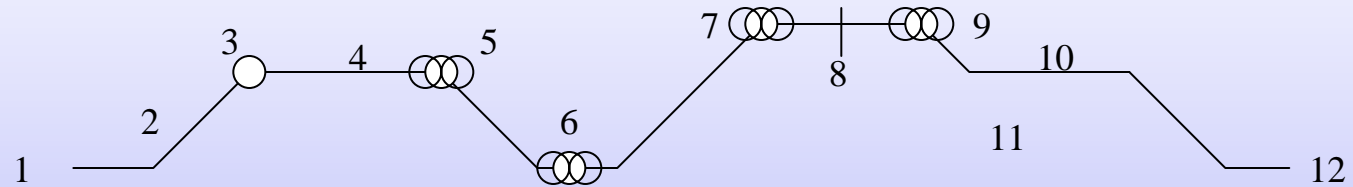
2001 - '03 Convertible MILITARY MiAVs

Mission Challenge:

MOUT Capable MILITARY Subscale UAV with High Dash Speed & Efficient Loiter

"We want a subscale UAV that can do it all." -Mr. Serh Ghee Lim, President, Singapore Technologies Aerospace Corp.

XQ-138 Design Mission:



Mission Stage	Endurance (min)	Elapsed Time (min)	Mission Stage	Endurance (min)	Elapsed Time (min)
1. Startup	1.0	1.0	7. Climb & HOGE 5 min	5.0	33.5
2. VTO & Climb	0.5	1.5	8. Release & HOGE 5 min	5.0	38.5
3. Xition	0.5	2.0	9. Xition & Descent	0.5	39.0
4. Cruise, 10 km, 50 kts	6.5	8.5	10. Cruise, 10 km, 50 kts	6.5	45.5
5. Xition & HOGE 10 min	10.0	18.5	11. Xition	0.5	46.0
6. Desc. & HOGE 10 min	10.0	28.5	12. VL & Shut-down	1.0	47.0

Mission Specification:

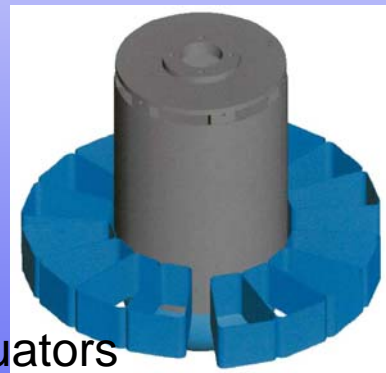
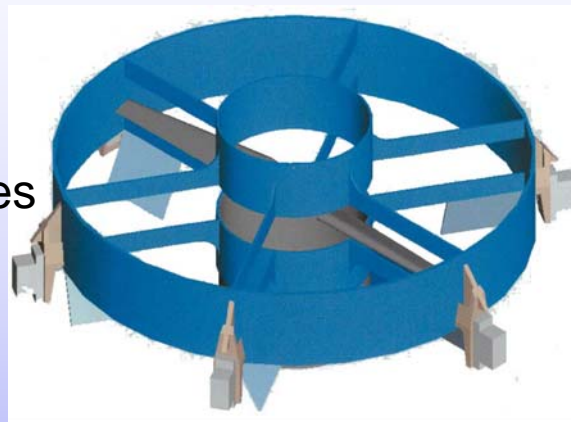
- Max. weight: 6 lb (2.7kg)
- All weather capable
- 25 kt gust penetration
- Com link: RF
- Dash speed: 80mph (130kph)
- Flight modes: 1st, 3rd person, fully autonomous w/waypoint navigation
- Mission Range: 10km
- 12"/hr (31cm/hr) rain
- 15g MOUT wall strike
- 500g P/L
- Sensors: B/W 0.001 lux, Color 0.1 lux, FLIR
- Design Mission Duration: 47 min.
- 100°F (38°C), 100% humidity
- Combat shotgun resistant @5m
- T/O distance: n/a

2001 - '03 Convertible MILITARY MiAVs

XQ-138 Design: MDO using best currently available technology

Rotor Guard

- turning vane flap servos
- electrical & fuel feed lines
- turning vanes
- turning vane flaps
- rotor

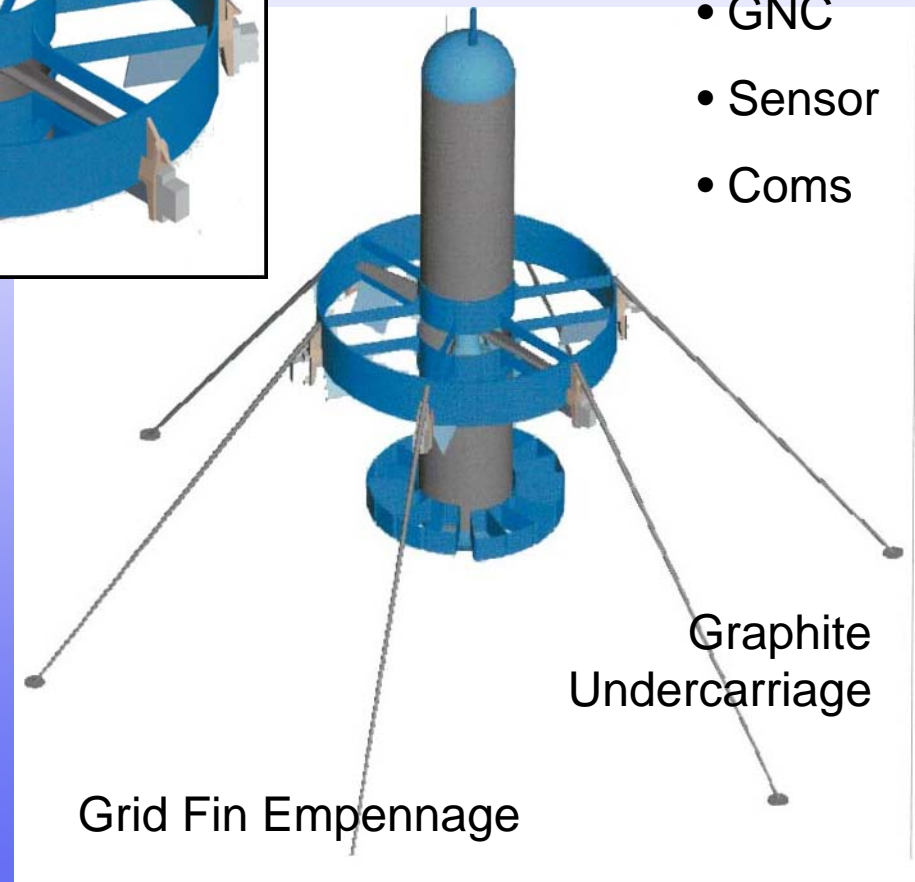


Lower Fuselage

- powerplant
- empennage actuators
- muffler assembly

Upper Fuselage

- fuel
- GNC
- Sensor
- Coms



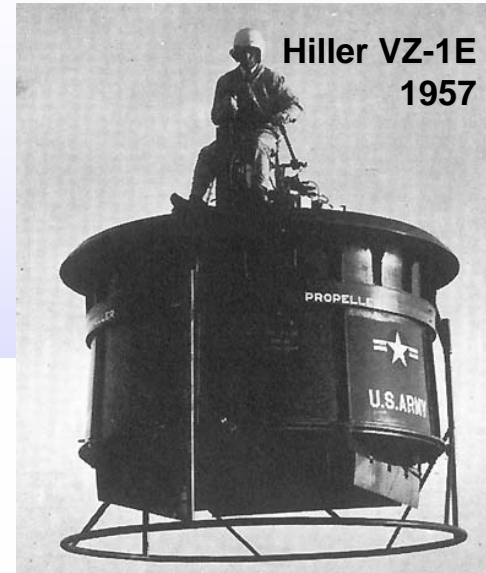
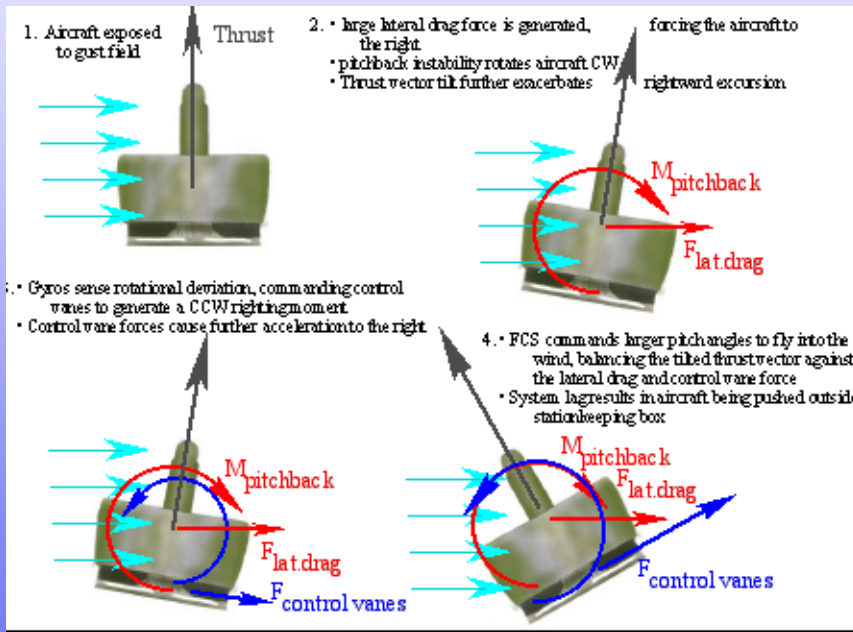
2001 - '03 Convertible MILITARY MiAVs

Coleopter Pitchback Instability: 50 years of Experience

“We didn’t have the control authority needed for the prevailing conditions.”

Gary Downs, Director Allied UAV Systems following catastrophic crash of the iSTAR at Ft. Eustis in light but gusty wind conditions. 10 September 2003 <http://www.uvonline.com>

Coleopter Pitchback Instability explained in OAV Proposal to DARPA 1/01



“Unfortunately, this effect limited the forward speed to a mere 26 kph (16 mph) and caused erratic handling in windy conditions.” Smithsonian Air and Space Museum on the Hiller VZ-1 aircraft http://www.nasm.si.edu/nasm/aero/aircraft/hiller_vz1.htm

2001 - '03 Convertible *MILITARY* MiAVs

**XQ-138 Flight Demonstration from LAV at Redstone Arsenal and Eglin AFB
Strong Gusty Conditions to 26 kts April - May 2002**

1. Aircraft loaded & preflighted



2. Aircraft Release



3. Vertical Ejection @ ~ 10 ft/s (~ 3m/s)



4. Clearing Launcher



5. Transition



6. Flyaway



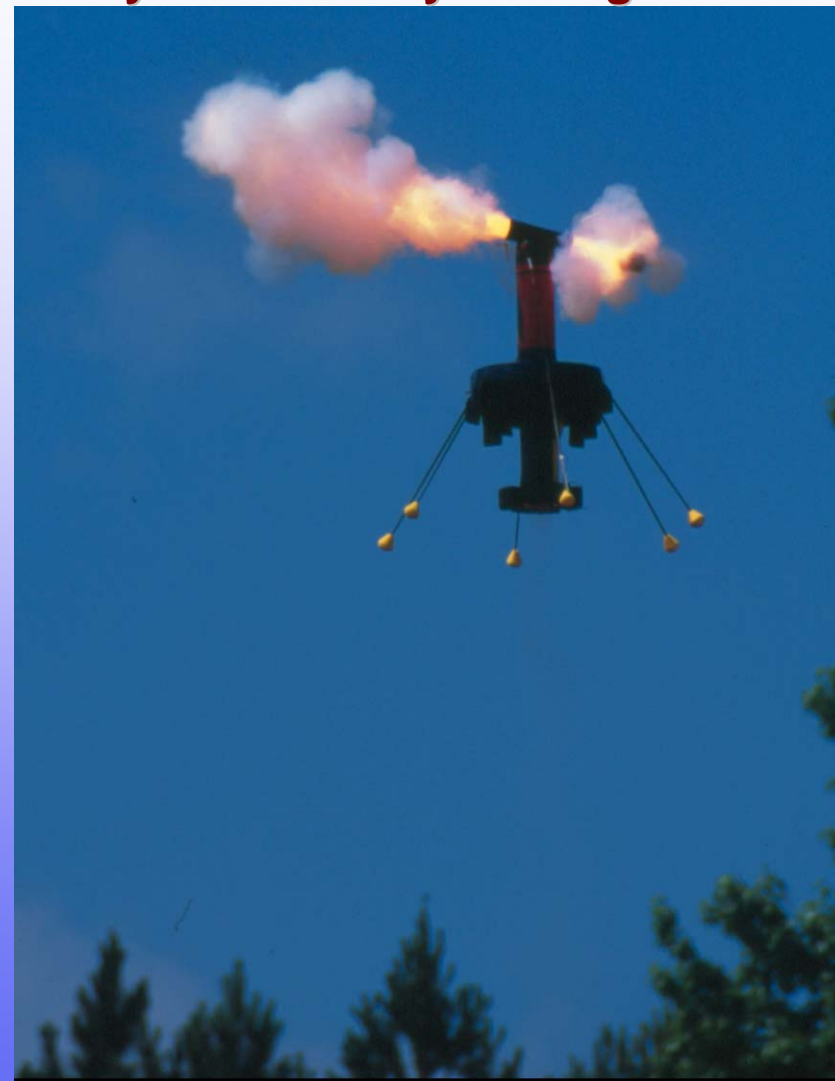
2001 - '03 Convertible *MILITARY* MiAVs

Autonomy Package Development 6/02 - 6/03

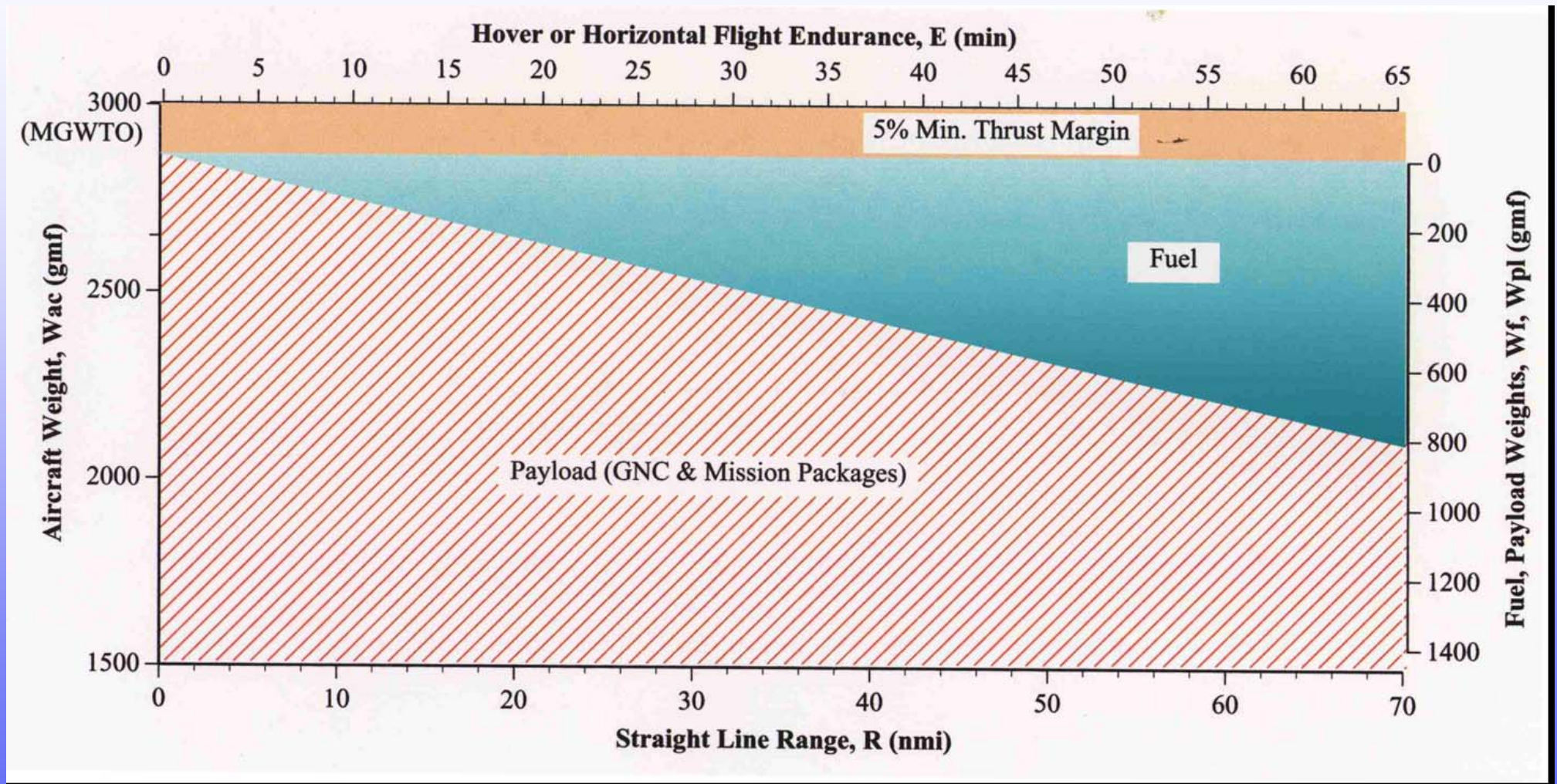
Demonstrated multiple waypoint navigation in hover mode flight



Payload Delivery Testing 7/03



2001 - '03 Convertible MILITARY MiAVs

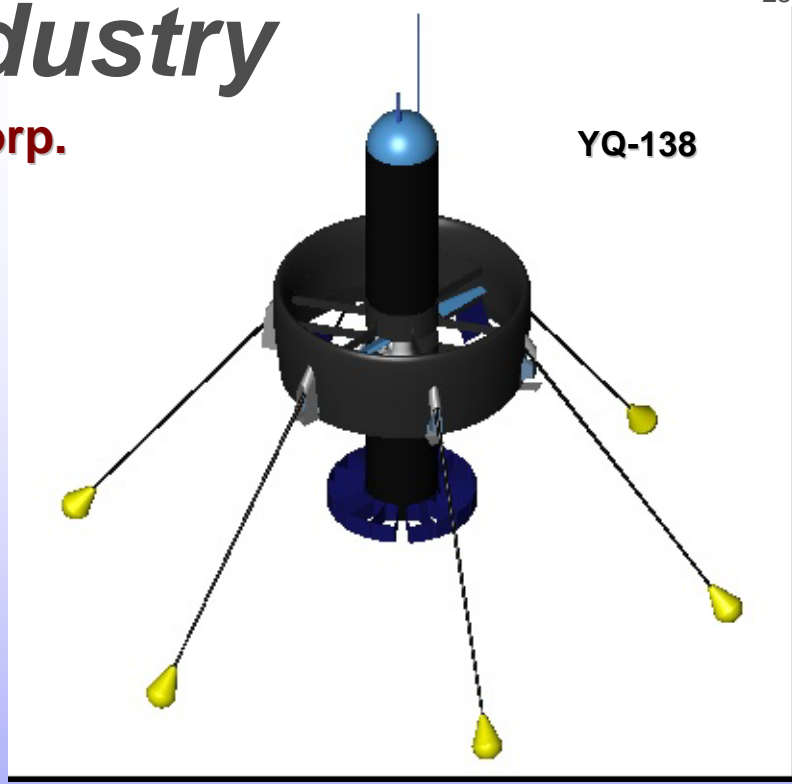
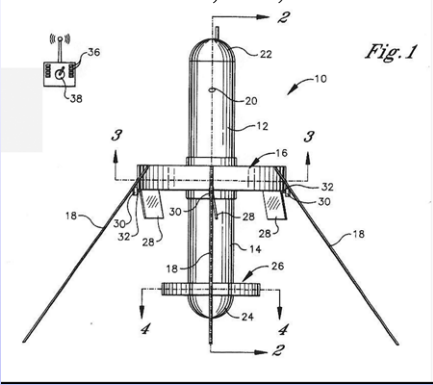


2003 Handoff to Industry

Purchased by Singapore Technologies Aerospace Corp.

Limited rate production scheduled 2nd qtr/04

US Pat. 6,502,787



Future variants:
Elastic, modular design = too many to cover

